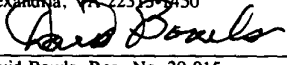


"Express Mail" label number **EV246529355US**

Date of deposit Aug 22, 2009

**PATENT**  
**091-0186**

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## **AUTOMATED COMPOSITE LAY-UP TO AN INTERNAL FUSELAGE MANDREL**

### **BACKGROUND OF THE INVENTION**

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**[001]** The present invention generally relates to fabrication of large composite structures and, more particularly, to automated composite lay-up of large aircraft fuselage sections.

10 **[002]** The structural performance advantages of composites, such as carbon fiber epoxy and graphite bismaleimide (BMI) materials, are widely known in the aerospace industry. Aircraft designers have been attracted to composites because of their superior stiffness, strength, and radar absorbing capabilities, for example. As more advanced materials and a wider variety of material forms have become available, aerospace usage of composites has increased.

15 Automated tape layer technology has developed to become a widely used automated process for fabrication of large composite structures such as wing panels and empennage. Current tape layer technology has been improved to offer flexibility in process capabilities required for a wide variety of aerospace components. As aerospace industry tape laying applications achieve material

20 lay up rates, for example, that may help control the manufacturing cost of large composite structures, new and innovative applications for tape layers may be defined, such as the automated tape lay-up of large aircraft fuselage sections, for example, 15 to 20 feet in diameter.

**[003]** Automated tape laying machines typically are gantry style machines

25 that may have, for example, ten axes of movement with 5-axis movement on the

gantry and 5-axis movement on the delivery head. A typical automated tape layer consists of a gantry structure (parallel rails), a cross-feed bar that moves on precision ground ways, a ram bar that raises and lowers the material delivery head, and the material delivery head which is attached to the lower end of the ram bar. Commercial tape layers are generally configured specifically for lay up of flat or mildly contoured laminate applications using either flat tape laying machines (FTLM) or contour tape laying machines (CTLM). On a gantry style tape layer, tooling (or a flat table) is commonly rolled under the gantry structure, secured to the floor, and the machine delivery head is then initialized to the lay up surface.

**[004]** Figure 1 provides an illustration of a typical tape laying machine material delivery head 100. Delivery heads for FTLM and CTLM machines are basically the same configuration as that of delivery head 100 shown in Figure 1. The delivery heads on commercial automated tape layers are typically configured to accept material widths of 75 mm (3"), 150 mm (6"), and 300 mm (12"). Flat tape layers typically use material in 150 mm (6") and 300 mm (12") widths. Contour tape layers typically use material in 75 mm (3") and 150 mm (6") widths. CTLM systems normally use the 3" or 6" wide material when laying up off flat plane contour surfaces. Material 102 for tape layers generally comes in large diameter spools. The tape material 102 has a backing paper 106, which must be extracted as the prepreg (resin pre-impregnated fiber) is applied to the tool surface 108. The spool of material typically is loaded into the delivery head supply reel 104 and threaded through the upper tape guide chute and past the cutters 110. The material 102 then passes through the lower tape guides, under the segmented compaction shoe 112, and onto a backing paper take up reel 114. The backing paper is extracted and wound on a take up roller of paper take up reel 114. The delivery head 100 makes contact with the tool surface 108 and the tape material 102 is "placed" onto the tool surface 108 with compaction pressure. The tape laying machine typically lays tape on the tool surface 108 in a computer programmed path (course), cuts the material 102 at a

precise location and angle, lays out tail, lifts delivery head 100 off the tool surface 108, retracts to the course start position, and begins laying the next course. The delivery head 100 may have an optical tape flaw detection system that signals the machine control to stop laying tape material 102 when a flaw  
5 has been detected. The delivery head 100 also typically has a heating system 116 that heats the prepreg materials to increase tack levels for tape-to-tape adhesion. Heated tape temperatures generally range from 80 F to 110 F.

**[005]** Fiber placement is a similar process in which individual prepreg fibers, called tows, are pulled off spools and fed through a fiber delivery system  
10 into a fiber placement head, which is similar to delivery head 100 shown in Figure 1. In the fiber placement head, tows may be collimated into a single fiber band and laminated onto a work surface, which can be mounted between a headstock and tailstock. When starting a fiber band or course, the individual tows are fed through the head and compacted onto a surface -such as surface  
15 108. As the course is being laid down, the head 100 can cut or restart any of the individual tows. This permits the width of the fiber band to be increased or decreased in increments equal to one tow width. Adjusting the width of the fiber band eliminates excessive gaps or overlaps between adjacent courses. At the end of the course, the remaining tows may be cut to match the shape of the ply  
20 boundary. The head may then be positioned to the beginning of the next course. During the placement of a course, each tow is dispensed at its own speed, allowing each tow to independently conform to the surface 108 of the part. Because of this, the fibers are not restricted to geodesic paths. They can be steered to meet specified design goals. A rolling compaction device,  
25 combined with heat for tack enhancement, laminates the tows onto the lay-up surface 108. This action of pressing tows onto the work surface (or a previously laid ply) adheres the tows to the lay-up surface 108 and removes trapped air, minimizing the need for vacuum debulking. It also allows the fiber to be laid onto concave surfaces.

30 **[006]** A fiber placement head, like the tape laying head, may be provided

with several axes of motion, using an arm mechanism, for example, and may be computer numeric controlled. The axes of motion may be necessary to make sure the head 100 is normal to the surface 108 as the machine is laminating tows. The machine may also have a number of electronic fiber tensioners, which may be mounted, for example, in an air conditioned creel. These tensioners may provide individual tow payout and maintain a precise tension. The head 100 may precisely dispense, cut, clamp, and restart individual prepreg tows.

[007] In the quest to automate the placement of composite materials at a high rate - to make the use of composites economical compared to conventional methods of fuselage fabrication - efforts have been focused at wrapping around a male mandrel, i.e. tool. Today's composite, fiber material placement processes and equipment have used male mandrels exclusively, wrapping tape layers on the outside surface of the tool - such as tool surface 108. One problem with this approach is that controlling the outside surface of the part - such as a fuselage section - is not possible without transferring the part to a female tool or clam shell type tooling.

[008] As can be seen, there is a need for fabrication of composite parts using an automated lay-up machine that allows material placement directly to an outside mold surface, from inside a tool, allowing greater control and accuracy forming the exterior surface of the part. There is also a need for fabrication of composite parts using an automated lay up machine that eliminates expansion and transfer of the part to another tool, resulting in less defects and higher surface quality for the part. Moreover, there is a need for an automated lay-up machine for composite fabrication of large diameter fuselage sections.

#### SUMMARY OF THE INVENTION

[009] In one aspect of the present invention, a device for automated

composite lay-up includes a tool having an axis of rotation. The tool includes a mandrel with an outside mold surface of a part to be manufactured. The outside mold surface is on the inside of the mandrel. The device also includes at least one circular ring surrounding the tool and the mandrel and concentric  
5 with the axis of rotation. The tool is rotated about the axis of rotation and composite material is delivered directly to the outside mold surface on the inside of the mandrel.

**[010]** In another aspect of the present invention, a device for automated composite lay-up includes a tool with a mandrel. The mandrel has an interior  
10 mandrel surface that conforms to an outside mold line of a part. At least one circular ring is attached to the tool so that the circular ring surrounds the tool and the mandrel. A bearing contacts the circular ring, and the circular ring rotates supported by the bearing so that the tool and the mandrel rotate concentrically with the circular ring about an axis of rotation passing through the  
15 center of the circular ring.

**[011]** In still another aspect of the present invention, a device for automated composite lay-up includes a tool having a mandrel and a circular ring having a center. The mandrel has an interior mandrel surface that conforms to an outside mold line of a part. The circular ring surrounds the mandrel and is  
20 attached to the mandrel. A bearing cradle includes a plurality of bearings, and at least one bearing of the plurality of bearings contacts the circular ring. The bearing cradle supports the weight of the tool through the plurality of bearings, and the circular ring rotates supported by the bearings so that the mandrel rotates concentrically with the circular ring about an axis of rotation passing  
25 through the center of the circular ring.

**[012]** In yet another aspect of the present invention, an aircraft part manufacturing device for automated composite lay up includes a tool having a mandrel and a circular ring having a center. The mandrel has an interior  
mandrel surface that conforms to an outside mold line of a part. The circular  
30 ring surrounds the mandrel and is attached to the mandrel. A bearing cradle

includes a plurality of bearings so that at least one bearing of the plurality of bearings contacts the circular ring. The bearing cradle supports the weight of the tool through the plurality of bearings. The circular ring rotates supported by the bearings so that the mandrel rotates concentrically with the circular ring about an axis of rotation passing through the center of the circular ring. The bearing cradle is moveable. A material delivery head delivers composite material directly to the outside mold line on the interior mandrel surface. A gantry beam is cantilever supported; the gantry beam is moveable relative to the tool; and the gantry beam supports the material delivery head inside the interior mandrel surface of the mandrel. A connecting mechanism connects the material delivery head to the gantry beam, so that the connecting mechanism provides axial motion of the material delivery head relative to the interior mandrel surface; the connecting mechanism provides motion of the material delivery head relative to the interior mandrel surface in a direction normal to the interior mandrel surface; and the connecting mechanism provides rotation of the material delivery head relative to the interior mandrel surface about an axis normal to the interior mandrel surface.

**[013]** In a further aspect of the present invention, an aircraft part manufacturing device for automated composite lay up includes means for rotating a mandrel about an axis of rotation. The mandrel has an outside mold surface on the inside of the mandrel. The device also includes means for supporting a material delivery head above the outside mold surface; and means for placing a composite fiber material inside the mandrel onto the outside mold surface.

**[014]** In a still further aspect of the present invention, a method is disclosed for automated composite lay up on an interior mandrel surface of a tool having an axis of rotation. The mandrel has an outside mold surface on the inside of the mandrel. The method includes rotating the mandrel about an axis of rotation; supporting a material delivery head above the outside mold surface; and placing a composite fiber material inside the mandrel onto the outside mold

surface.

[015] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

[016] Figure 1 is a diagram of a typical tape laying machine material delivery head, as known in the art;

10 [017] Figure 2 is a perspective illustration of an aircraft part manufacturing device for automated composite lay up, according to one embodiment of the present invention;

[018] Figure 3 is a perspective illustration of an aircraft part manufacturing device for automated composite lay up, according to another embodiment of the present invention;

15 [019] Figure 4 is a perspective illustration of an aircraft part manufacturing device for automated composite lay up, according to still another embodiment of the present invention;

[020] Figure 5 is a perspective illustration of an aircraft part manufacturing device for automated composite lay up, according to yet another embodiment of the present invention; and

20 [021] Figure 6 is a perspective illustration of an aircraft part manufacturing device for automated composite lay up, according to yet another embodiment of the present invention.

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#### DETAILED DESCRIPTION OF THE INVENTION

[022] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the

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general principles of the invention, since the scope of the invention is best defined by the appended claims.

**[023]** Broadly, one embodiment of the present invention provides fabrication of parts made of composite materials, which may be used, for example, in the manufacture of commercial and military aircraft. In one embodiment, an automated lay-up machine allows material placement directly to an outside mold surface and eliminates prior art techniques of expansion and transfer of the part to another tool, allowing greater control and accuracy over the prior art in forming the exterior surface of the part and resulting in less defects and higher surface quality compared to parts fabricated according to the prior art. In one embodiment, an automated lay-up machine may be ideally suited for composite fabrication of fuselage sections having large diameter, for example, from 15 to 20 feet. The automated lay-up machine may place the composite materials directly to the outside mold surface from inside the tool. Such operation would be difficult for prior art fuselage fabrications - such as Premier I and Horizon business jets made by Raytheon, Inc. - because of the relatively small diameter of the business jet fuselage, which may necessitate conventional outside lay-up using a male mandrel. Automated tape and fiber lay-up equipment and gantry could easily fit, however, within a large commercial aircraft fuselage, for which the diameter could reach in excess of 20 feet. In addition, alternative embodiments of the present invention allow for orientation of the mold or lay-up mandrel at any angle or attitude, for example, horizontal, vertical, or tilted, that may facilitate the fabrication of long fuselage sections that may be in the range, for example, of 30 to 40 feet or more in length.

**[024]** Because use of the tool of one embodiment eliminates prior art techniques of building on a male mandrel and transferring to a female mandrel tool, the problems inherent in such prior art techniques may be avoided. For example, using prior art tools and processes, graphite or other fibers wrapped in the hoop direction around a fuselage do not allow the composite to expand out and conform properly to the female tool, creating difficulty for expanding the



part, so that the part does not make proper contact with, or conform to the female tool. Parts made using an embodiment of the present invention may be expected to be of higher quality and have fewer exterior surface defects because the prior art need to expand the part has been eliminated, eliminating  
5 those problems associated with the prior art fabrication tools and techniques.

[025] Referring now to the figures, wherein like items are referenced with the same numerals, and in particular, referring to Figure 2, an aircraft part manufacturing device 200 for automated composite lay up is illustrated in accordance with one embodiment. Device 200 may include a tool 202 that may  
10 have an axis of rotation 204. Tool 202 may be situated so that axis of rotation 204 is placed at any desirable angle or attitude relative to horizontal. The example embodiment illustrated in Figure 2 shows a horizontal configuration of device 200 in which the attitude of axis of rotation 204 may be horizontal or nearly horizontal, as shown in Figure 2, or also may be tilted. Other  
15 configurations and attitudes, however, are contemplated. For example, Figure 6 shows one possible configuration in which axis of rotation 204 may be placed vertically or at attitudes closer to vertical than may be practical with the configuration shown in Figure 2. Tool 202 may have a mandrel 206, which may be approximately cylindrical, or symmetrical about axis of rotation 204, as  
20 shown in Figure 2. The inside of mandrel 206 may have an interior mandrel surface 208, which may conform to an outside mold surface or an outside mold line (OML) of an aircraft part to be manufactured. Interior mandrel surface 208 may also be referred to as the "outside mold surface" or "OML". Tool 202 may include stiffeners 210 that provide extra strength and stiffness to support  
25 outside mold surface, i.e., interior mandrel surface 208, of mandrel 206 while adding a minimal amount of extra weight to tool 202.

[026] Device 200 may include circular rings 212 and 214, which may be integral with tool 202 or may be attached to tool 202. Stiffeners 210 may also attach to circular rings 212 and 214 to provide extra integrity of circular rings  
30 212 and 214 with tool 202. Circular rings 212 and 214 may attach to stiffeners

210 as well as to mandrel 206 to provide extra strength and rigidity of the attachment of circular rings 212 and 214 to mandrel 206 of tool 202. Circular rings 212 and 214 may be in contact with bearings 216, which may support rotation of tool 202 and mandrel 206. Circular rings 212 and 214 may surround  
5 tool 202, and mandrel 206, and may be concentric with axis of rotation 204 so that rotation of circular rings 212 and 214 on bearings 216 rotates mandrel 206 about its axis of rotation 204. In other words, circular rings 212 and 214 rotate supported by bearings 216 so that mandrel 206 rotates concentrically with circular rings 212 and 214 about an axis of rotation 204 passing through the  
10 center of circular rings 212 and 214. Bearings 216 may be held by a bearing cradle 218 that may support the weight of tool 202, including mandrel 206 and circular rings 212 and 214, through the bearings 216. Bearing cradle 218 may be moveable, for example, to provide transport of tool 202 and the part being manufactured from one stage of a manufacturing process to another.

15 **[027]** Device 200 may also include a gantry beam 220 disposed to access the inside of the mandrel 206. Gantry beam 220 may be cantilever supported, for example, by cantilever supports 222. Cantilever supports 222 may be fitted with rollers 224. Gantry beam 220 may be supported as a cantilever beam using rollers 224 so that gantry beam 220 is moveable relative to tool 202.  
20 Gantry beam 220 may be further supported by tail stocks 226 so that gantry beam 220 becomes either fully supported as a beam between tail stocks 226 and cantilever supports 222 or becomes partially cantilever supported by cantilever supports 222 and partially supported as a beam between tail stocks 226 and cantilever supports 222. Tail stocks 226 may, for example, also be  
25 fitted with rollers - such as rollers 224 - or may otherwise be made to "telescope" - so that gantry beam 220 remains moveable relative to tool 202 when tail stocks 226 are connected to gantry beam 220 for support. Tail stocks 226 may be removable from gantry beam 220 and moveable so that tool 202 may be removable from gantry beam 220, for example, as tool 202 may be  
30 moved from one stage of a manufacturing process to another.

**[028]** Device 200 may further include a composite material delivery head 228. Material delivery head 228, for example, may be similar to material delivery head 100, such as a flat tape laying machine, contour tape laying machine, or fiber placement head. Material delivery head 228, for example, may be an adaptation of an existing delivery head, such as a tape laying or fiber placement head, as needed to meet surface contour requirements, as the contour of interior mandrel surface 208 may vary widely depending on the aircraft part which aircraft part manufacturing device 200 is being used to manufacture. For example, tape laying heads may be used for material delivery heads 228 when the tool 202 and interior mandrel surface 208 cross sections remain mostly constant, as seen in Figure 2. By the same token, fiber placement heads may be used for material delivery heads 228 when the cross sections of tool 202 and interior mandrel surface 208 change significantly along the length of the tool 202, for example, as shown in Figure 3.

**[029]** Material delivery head 228 may be supported above the interior mandrel surface 208 inside of mandrel 206, as shown in Figure 2, so that gravity may be used to aid in the delivery of composite material to interior mandrel surface 208. Composite material may be delivered in courses 230 directly to the outside mold line on the interior mandrel surface 208. For example, gantry beam 220 may support material delivery head 228 inside interior mandrel surface 208 of mandrel 206, so that composite material is delivered directly to the outside mold surface on the inside of mandrel 206.

**[030]** Device 200 may include a connecting mechanism 232 that may connect material delivery head 228 to gantry beam 220. Connecting mechanism 232 may provide axial motion relative to interior mandrel surface 208, i.e., motion in a direction parallel to axis of rotation 204, of material delivery head 228 along gantry beam 220. Device 200 may also include an arm mechanism 234 that may connect material delivery head 228 to gantry beam 220. Arm mechanism 234 may provide motion of material delivery head 228 relative to the outside mold surface, i.e., interior mandrel surface 208, of

mandrel 206. Connecting mechanism 232 and arm mechanism 234 are more clearly shown in Figure 3 and are further described below.

**[031]** In operation, material delivery head 228 may translate along the entire length of the tool 202 while tool 202 rotates, allowing the material delivery head 228 to place material in courses 230 over the entire tool surface, i.e., interior mandrel surface 208. The courses 230 of composite material may be laid down in various patterns on interior mandrel surface 208 depending on the relative motion between material delivery head 228 and tool 202. Gantry beam 220 may provide an axial motion of material delivery head 228, for example, by movement of gantry beam 220 using rollers 224, as described above. Alternatively, gantry beam 220 may be supported at one end by tail stock 226 during operation of material delivery head 228, and connecting mechanism 232 may provide an axial motion of material delivery head 228 by moving material delivery head 228 along gantry beam 220.

**[032]** At the same time, tool 202 may or may not be rotated. For example, if material delivery head 228 is held stationary while tool 202 is rotated, a course 230 of composite material may be laid down in a circumferential, or hoop, direction, as shown in Figure 2. Also for example, if material delivery head 228 is moved axially while tool 202 is held stationary a course 230 of composite material may be laid down in an axial direction, as shown in Figure 5. If both material delivery head 228 is moved axially while tool 202 is rotated, a course 230 of composite material may be laid down in a helical pattern, with the helix angle depending on the relative velocities of motion and rotation.

**[033]** Material delivery head 208 may be controlled in coordination with the rotation of tool 202, mandrel 206, and interior mandrel surface 208, for example, by using existing numerical control (NC) or computer numerical control (CNC) programming software to control the material delivery head 208 and tool 202 simultaneously. For example, rotation of tool 202 may be driven through bearings 216 using CNC control coordinated with CNC control of the material delivery heads 208.

[034] Referring now to Figure 3, an aircraft part manufacturing device 240 for automated composite lay up is illustrated in accordance with another embodiment. Interior mandrel surface 208 of mandrel 206 of tool 202 may have a non-constant cross section as seen in Figure 3. Mandrel 206 is shown in  
5 partial cut-away view in Figure 3 to aid viewing other parts of the drawing. As shown in Figure 3, circular ring 214 may have a greater thickness 244 than thickness 242 of circular ring 212. Thus, the thicknesses 242, 244 of circular rings 212, 214 may be used to compensate for a mandrel 206 having non-constant cross sections so that when circular rings 212 and 214 are rotated  
10 supported by bearings 216, mandrel 206 may rotate concentrically with circular rings 212 and 214 about an axis of rotation 204 passing through the center of circular rings 212 and 214.

[035] Device 240 may include connecting mechanism 232 that may connect material delivery head 228 to gantry beam 220. Material delivery head  
15 228 may be a fiber placement head, for example, to aid in the laying down of material on the more complex contour of mandrel 206 shown in Figure 3. A creel 233 may also be supported on connecting mechanism 232. Creel 233 may store material, for example, for supplying prepreg tows to fiber placement material delivery head 228. Connecting mechanism 232 may provide axial  
20 motion or positioning adjustment of material delivery head 228 relative to interior mandrel surface 208 and may also provide motion of material delivery head 228 along gantry beam 220 if gantry beam 220 is held stationary during operation of material delivery head 228, for example, using tail stocks such as tail stocks 226 shown in Figure 2. Connecting mechanism 232 may provide  
25 motion of material delivery head 228 relative to interior mandrel surface 208 in a direction normal, i.e. perpendicular, to interior mandrel surface 208. Connecting mechanism 232 also may provide rotation of material delivery head 228 relative to interior mandrel surface 208 about an axis normal to interior mandrel surface 208.

30 [036] Device 240 may also include an arm mechanism 234 that may

connect material delivery head 228 to gantry beam 220 or to connecting mechanism 232 as shown in Figure 3. Arm mechanism 234 may provide motion of material delivery head 228 relative to interior mandrel surface 208 in a direction normal to interior mandrel surface 208. Arm mechanism 234 also may provide rotation of material delivery head 228 relative to interior mandrel surface 208 about an axis normal to interior mandrel surface 208. Arm mechanism 234 also may provide motion or position adjustment of material delivery head 228 relative to interior mandrel surface 208 in an axial direction relative to interior mandrel surface 208. Arm mechanism 234 also may provide motion or position adjustment of material delivery head 228 relative to interior mandrel surface 208 in a circumferential, or hoop, direction relative to interior mandrel surface 208.

**[037]** Referring now to Figure 4, an aircraft part manufacturing device 250 for automated composite lay up is illustrated in accordance with another alternative embodiment. Interior mandrel surface 208 of mandrel 206 of tool 202 may have a non-constant cross section that closes off at one end as seen in Figure 4. For example, such a mandrel might be used to build a nose cone or tail cone of an aircraft. Mandrel 206 is shown in partial cut-away view in Figure 4 to aid viewing other parts of the drawing. As shown in Figure 4, mandrel 206 may be supported by circular ring 212 at one end of mandrel 206, and may be supported at the other, closed off, end of mandrel 206 by a hub 252. Hub 252, for example, may be attached to tool 202 and may rotationally support tool 202 so that mandrel 206 rotates about axis of rotation 204 passing through the center of hub 252 and the center of circular ring 212.

**[038]** Device 250 may include connecting mechanism 232 that may connect material delivery head 228 to gantry beam 220. In Figure 4, gantry beam 220 appears as a pair of rails 221 supporting connecting mechanism 232, and on which connecting mechanism 232 may move axially, with respect to axis of rotation 204, back and forth. Connecting mechanism 232 appears in Figure 4 as a large platform which may move back and forth on supported rails 221 of gantry beam 220. Material delivery head 228 may be a fiber placement head,

for example, to aid in the laying down of material on the more complex contour of mandrel 206 shown in Figure 4. Connecting mechanism 232 may also support a creel 233. Creel 233 may, for example, store material for supplying prepreg tows to fiber placement material delivery head 228 and may provide a location for control electronics and mechanisms for controlling connecting mechanism 232, arm mechanism 234, and material delivery head 228.

**[039]** As described above, connecting mechanism 232 may provide axial motion or positioning adjustment for arm mechanism 234 and material delivery head 228 relative to interior mandrel surface 208 and may also provide motion of material delivery head 228 along gantry beam 220. Arm mechanism 234, as described above, may provide motion of material delivery head 228 relative to interior mandrel surface 208 in a direction normal to interior mandrel surface 208; rotation of material delivery head 228 about an axis normal to interior mandrel surface 208; motion in an axial direction relative to interior mandrel surface 208; and motion in a circumferential, or hoop, direction relative to interior mandrel surface 208.

**[040]** Figure 5 illustrates yet another embodiment of an aircraft part manufacturing device 260. Figure 5 shows material delivery head 228 laying a course 230 of composite material to an OML at an interior mandrel surface 208 of a mandrel 206 of a tool 202 (the complete tool 202 is not shown in Figure 5). As shown in Figure 5, material delivery head 228 may be supported above interior mandrel surface 208 by a gantry beam 220. Connecting mechanism 232 may provide axial motion and positioning of material delivery head 228 along gantry beam 220 and may support and connect arm mechanism 234 to gantry beam 220. Arm mechanism 234, as described above, may provide motion of material delivery head 228 relative to interior mandrel surface 208 in a direction normal to interior mandrel surface 208, i.e., up and down as seen in Figure 5; rotation of material delivery head 228 about an axis normal to interior mandrel surface 208; motion in an axial direction relative to interior mandrel surface 208; and motion in a circumferential, or hoop, direction relative to

interior mandrel surface 208. Figure 5 illustrates that it is contemplated that material delivery head 228 may be implemented by a tape laying machine or other material delivery head capable of delivering very wide courses of material, such as may be provided by composite tape or cloth.

5   **[041]**     Figure 6 illustrates another embodiment of an aircraft part manufacturing device 270. Figure 6 shows material delivery head 228 laying a course 230 of composite material to an OML at an interior mandrel surface 208 of a mandrel 206 of a tool 202. Tool 202 may include a ring 212 supported on bearings. As shown in Figure 6, material delivery head 228 may be supported  
10   above interior mandrel surface 208 by a gantry beam 220. Connecting mechanism 232 may provide axial motion and positioning of material delivery head 228 along gantry beam 220 and may support and connect arm mechanism 234 to gantry beam 220. Arm mechanism 234, as described above, may provide motion of material delivery head 228 relative to interior  
15   mandrel surface 208 in a direction normal to interior mandrel surface 208, i.e., up and down relative to interior mandrel surface 208 and at an oblique angle with respect to horizontal as seen in Figure 6. Arm mechanism 234, as described above, may also provide rotation of material delivery head 228 about an axis normal to interior mandrel surface 208; motion in an axial direction  
20   relative to interior mandrel surface 208; and motion in a circumferential, or hoop, direction relative to interior mandrel surface 208.

**[042]**     A method for automated composite lay up on an interior mandrel surface - such as interior mandrel surface 208 of mandrel surface 206 of tool 202 - may include rotating the mandrel about an axis of rotation - such as axis  
25   of rotation 204 - which may have any angle or attitude including, for example, horizontal, vertical, and tilted. The interior mandrel surface may conform to the outside mold surface, or OML, of a part to be manufactured. The method may also include supporting a composite material delivery head - such as material delivery heads 228, which may be composite tape laying machines or fiber  
30   placement heads, for example - above the interior mandrel surface inside the



mandrel and placing composite fiber onto the interior mandrel surface, i.e., onto the outside mold surface of the part.

**[043]** The method may also include rotationally supporting the mandrel on a bearing in contact with a circular ring surrounding the mandrel - such as bearings 216 contacting circular rings 212 and 214 surrounding and supporting mandrel 206. The method may include supporting the bearing in a bearing cradle and supporting the weight of said mandrel, the tool, and said circular ring using the bearing cradle.

**[044]** The method may also include supporting the material delivery head from a gantry beam - such as gantry beam 220 - and supporting one end of the gantry using a tail stock - such as tail stock 226. The method may include providing axial motion of the material delivery head along the gantry beam, for example, by using a connecting mechanism such as connecting mechanism 232. The method may provide a circumferential position adjustment of the material delivery head in a hoop direction relative to the interior mandrel surface, an axial position adjustment of the material delivery head relative to the mandrel surface, motion of the material delivery head in a direction normal to the mandrel surface, and rotation of the material delivery head about an axis normal to the mandrel surface, for example, by using mechanisms that connect the material delivery head to the gantry beam - such as connecting mechanism 232 and arm mechanism 234.

**[045]** It should be understood, of course, that the foregoing relates to preferred embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims.